that a classification based on form is not practicable. Each pair is named, some of the names indicating the form, as in the case of the rhomboid and teres major; some indicating action, as the levator and the supinator; some indicating location, as intercostal and

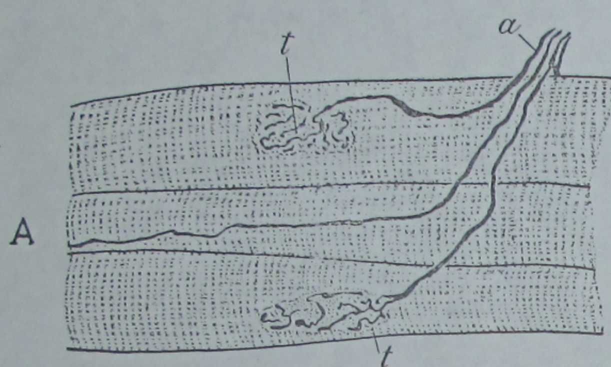

FIG. 1.—Muscle magnified, showing the muscle fibers and the nerve fibers. (Gray.)

supraspinatus; a few are named from the bones they join, as the brachioradialis and the sternomastoid.

Each muscle is composed of thread-like fibers, the number in a muscle varying from a few hundred to several hundred thousand. Each muscle fiber is an independent unit, having its own individual connection with the nervous system by a nerve fiber, through which

FIG. 2.—Fibers of muscle and tendon, showing striping and nuclei in the muscle fibers and a sensory nerve ending in the tendon. (Klein.)

it receives the influences that control its action. The muscle fibers vary in length from 200 to 1000 times their width, and lie close together, parallel to one another, with minute spaces between for the lymph on which they feed and into which they pour their

waste products. The fibers are too small to be seen readily with the unaided eye; they can be so stained that when seen through a microscope both the muscle and nerve fibers are visible. Notice in Fig. 1 the parallel muscle fibers and the smaller and more darkly stained nerve fibers (*a*) going to them and terminating in the motor endings (*t*).

Fig. 2 shows nuclei and the junction of muscle and tendon. The muscle fibers are shown below and the tendon above. The muscle fibers are seen to be crossed laterally by alternate bands of dark and light, and in each of them are seen the dark oblong nuclei irregularly placed. Each fiber is really a cylindrical mass of jelly-like protoplasm enclosed in a thin and transparent membrane called the sarcolemma. The sarcolemma keeps the protoplasm of the different fibers from merging into a single mass of jelly and isolates each one from all the rest, so that they can act as separate units.

A portion of one muscle fiber, highly magnified, is shown in Fig. 3. Notice that here we are observing the finer structure of a single muscle fiber, not a muscle. Fine threads running lengthwise of the fiber have on them certain enlargements, alternately spherical and cylindrical. The fine threads are called fibrils, and the clear space between them is filled with a semiliquid substance called sarcoplasm. It is readily seen that the enlargements on the fibrils, regularly placed, are what give the striped appearance of muscle fibers under lower magnification. It is now believed that all quick action of muscles is performed by the fibrils, while slower changes in tension and condition are due to the sarcoplasm. In the arrangement of fibers into a muscle they are usually grouped into bundles, each bundle having a sheath, and then the bundles are bound together by the sheath of the muscle. The fibers of many muscles are joined directly to the bones, but more often there is a strip of flexible tissue called a tendon (Fig. 2), to which the fibers join and which connects them with the bone. Each fiber is attached by its sarcolemma, and tendons are in reality formed by the fusion of all the sarcolemmas and sheaths of bundles with the sheath of the muscle.

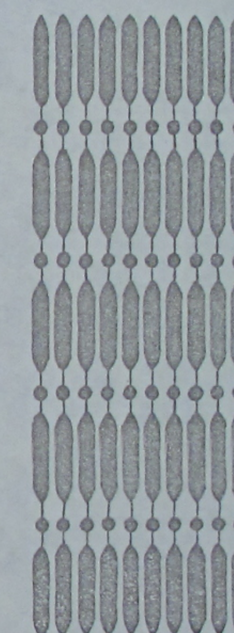

FIG. 3.—Portion of a single muscle fiber highly magnified. (Gerrish.)

Muscular work is done by a change in the form of the muscle called contraction, which includes a shortening and bulging out

sidewise. A relaxed muscle exerts a slight pull on its attachments because of its elasticity, but when it contracts it pulls with more force. The contraction is due to the shortening of the separate fibers, and each fiber as it shortens swells out laterally, stretching its sarcolemma and the other sheaths surrounding it and thus making the muscle feel harder to the touch than when relaxed. This hardening of muscles as they contract serves as a convenient test of muscular action, since it enables one to tell whether a certain muscle is taking part in a movement or whether it is idle.

The lateral swelling of a muscle in contraction may be used to exert force, as is easily shown by tying a band of cloth about the upper arm tightly and then forcibly bending the elbow. The muscles that bend the elbow swell out as they shorten and press out strongly on the band. Professional "strong men" often exhibit their great power in this way, breaking ropes and log-chains drawn tightly around the arm by a sudden bend of the elbow. Such a way of doing muscular work, however, is no more than a curious novelty; the bodily machinery is made to work by the pull of the muscles on the bones to which they are joined and its structure is developed on that plan. The lateral enlargement has this practical importance, that all the force used in stretching sheaths, clothing, or anything else that resists the free swelling of the muscles is so much force wasted. There will always be a small loss due to this cause, but each practice of an exercise diminishes it by making the sheaths more distensible from the repeated stretching they receive.

When a muscle contracts strongly it is apt to move both of the bones to which it is attached, but to simplify the problem it is usually assumed that the bone moving least is stationary. The point where the muscle joins the stationary bone is called the *origin* of the muscle, and its point of junction with the moving bone is called its *insertion*. Evidently the insertion is the place where the force is applied to the moving lever, and the distance from the insertion to the joint which serves as the axis of movement is the force-arm of the lever. Now it frequently happens in muscular exercise that the bone that acts as a lever in one exercise is stationary in another; for example, when one lies on his back and then lifts his feet the trunk is stationary and the lower limbs are levers, but when from the same position on the back he rises to sitting posture the limbs are stationary and the trunk is the lever. The same muscles do the work in the two cases, and it is evident that origins and insertions are reversed when the exercise is changed. The question as to which end of a muscle is origin and which is insertion depends therefore on the movement made. Although this is a matter of much importance in kinesiology, we shall for the

sake of clearness of description follow the custom of anatomists and call the end nearer the center of the body the origin. The true origin and insertion can be told with ease when any mechanical problem is involved.

The term "muscular tone" is frequently used in speaking of muscles and so needs explanation. Everyone is aware of the fact that we can contract a muscle at will to any desired degree of force up to its full strength and then can relax it at will down to any desired degree until complete relaxation is reached; in other words, instead of simply contraction and relaxation there are many possible grades of condition between the two. It can also be observed, although it is not so easy to notice, that there are different degrees of relaxation when we consider the muscles at rest. For example, if we feel of our muscles during or soon after a time of great excitement, such as a ball game or a thrilling play at the theater, we find them harder than usual, and further observation will show that we are less able than usual to keep from making all sorts of bodily movements, including talking, and that there is a feeling of tenseness in the muscles. After a night of good rest the tenseness and hardness are gone. These changes in the tension of muscles when they are not in ordinary contraction are called changes of "tone." They are caused by changes in the condition of the nervous system which are communicated to the muscles through the nerve fibers going to them. Muscular tone is greatest during excitement, less when one is quiet, still less when asleep; it is reduced still further by the action of anesthetics and most of all by paralysis or severing of the nerve fibers. A very high degree of tone shades off imperceptibly into mild contraction, as illustrated by shivering and by the tendency to act when excited.

Muscles that are much used are apt to have more tone than those used less; when this is the case between two antagonists the position of the joint upon which they act is apt to be out of normal position because of the greater tension of the one most used. For example, many women use the extensors of elbow so little and work with arms in front of the chest so much that their elbows are in a habitual posture of half-flexion. Habitual posture of the body depends much on muscular tone, and correction of posture is secured by improving the tone of one muscle and stretching its antagonist by the same exercise. Such exercises are more efficient before the tissues are matured by age.

The amount of work done by a contracting muscle is a combination of two elements of equal importance: the amount of force used and the distance or extent of movement. Stated mathematically, the amount of work is the product of the force by the distance ($W = F \times D$). One unit of work is the amount involved in

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exerting one unit of force through one unit of space, so that we measure work in gram-centimeters, foot-pounds, kilogram-meters, foot-tons, or car-miles, according to the units of force and distance employed.

In this connection it is important to notice two facts in the working of muscles: first, that the *force* a muscle can exert depends on the *number* and *size* of its fibers; second, that the *extent* through which it can contract depends on the *length* of its fibers. It follows from the first that the strength of muscles is proportional to their cross-section, with the understanding that this cross-section is taken at right angles to the fibers and includes all of them; the second is related to the fact that a muscle fiber can contract to half its full length. It has been found that human muscle in good condition can exert a force of 6 kilograms per square centimeter of cross-section, which is practically the same as 85 pounds to the square inch. A muscle that has 8 square inches of cross-section and fibers 6 inches long should therefore do 170 foot-pounds of work at a single contraction ($85 \times 8 \times 3 \div 12 = 170$).

The internal structure of muscles bears an important relation to the force and distance of their contractions, as the principles just stated indicate. We have noticed how greatly muscles differ in outward form; they differ quite as much in internal structure, which is a matter of arrangement of fibers. Two main types of structure are recognized, the *longitudinal* and the *penniform*, but there are many variations from each type. The longitudinal is the simpler of the two types; in its simplest form it can be well illustrated by the pronator quadratus (Fig. 71), a small muscle on the front of the forearm just above the wrist. This muscle consists of a single flat sheet of parallel fibers extending across the forearm, joining the radius on the outside and the ulna on the inside, covering a space about 2 inches square. This gives us fibers 2 inches long and therefore able to contract through about 1 inch of distance.

In order to illustrate how muscular structure is related to muscular work, let us assume, for the sake of argument, that this muscle has 800 fibers, each 4 cms. long and each able to exert a force of 1 gm. (Fig. 4, *A*). Under this supposition the muscle can exert a force of 800 gms. through a distance of 2 cms., doing 1600 gm. cms. of work at one contraction. Now suppose the muscle split lengthwise and the halves placed end to end, making a muscle of exactly the same bulk, with half as many fibers twice as long (Fig. 4, *B*); it can now pull with a force of 400 gms. through 4 cms. of distance, doing 1600 gm. cms. of work as before. Now let it be split in the same way again and its length doubled, giving a muscle of 200 fibers 16 cms. long (Fig. 4, *C*); now it can lift 200 gms. through 8 cms., doing the same amount of work. Evidently

the number of variations in the arrangement can be multiplied indefinitely, showing that a longitudinal muscle having a certain bulk will do its work in different ways according to number and length of its fibers, still doing the same amount of work in every case.

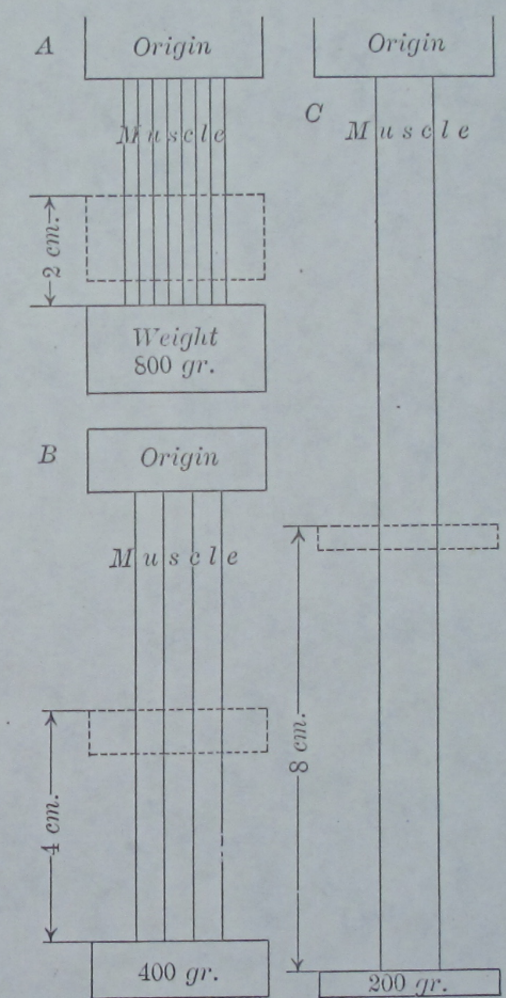

Fig. 4.—Diagram of three longitudinal muscles, showing how number and length of fibers affect power and extent of movement. *A* has 800 fibers 4 cms. long, *B* has 400 fibers 8 cms. long, and *C* has 200 fibers 16 cms. long. Arrows indicate extent of contraction.

As a matter of fact the many longitudinal muscles in the body illustrate just so many different arrangements on the same general plan, alike in consisting of parallel fibers running lengthwise of the muscle and differing in bulk and in the number and length of fibers. As two extreme instances we may take the sartorius (Fig. 92), which is a narrow band of extremely long fibers, suited to perform

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a movement with little force through an enormous distance, and one of the intercostals (Fig. 136), consisting of a great number of very short fibers joining two adjacent ribs and able to draw them nearer through a slight distance with a great force.

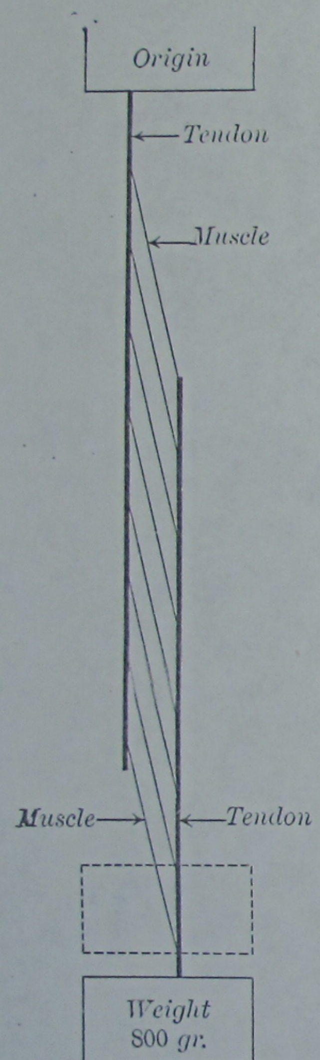

Fig. 5.—Diagram to show how a penniform arrangement of its fibers can give a long, slender muscle, like *C* in Fig. 4, the same lifting power as a short, thick muscle like *A*.

It is evident from the above that any muscle arranged on the longitudinal plan must be short and broad to have much strength of contraction; if it is long and slender it is sure to be weak, although it can shorten through a proportionately great extent. Fully three-fourths of all the muscles are situated where they need to exert more strength than a longitudinal muscle would have, while the greater extent of contraction would be wasted, and as a consequence the longitudinal plan is replaced by the penniform.

The simplest penniform arrangement is illustrated by the peroneus longus (Fig. 113). This muscle, almost as long and slender as the sartorius, must be able to lift the whole weight of the body and therefore must consist of a great many short fibers instead of a few long ones. To secure this structure a long tendon extends far up the outside of the leg parallel to the bone and the muscular fibers arise from the bone and join the tendon after extending diagonally downward and sideward for an inch or thereabout. The biceps (Fig. 50) presents a similar case. It is nearly a foot long but the movement it needs to make is not far from 3 inches; at the same time it must have great force. A longitudinal muscle would be able to shorten more than is useful here while it would lack force. To get the exact proportion of force and distance called for by the work to be done two tendons extend downward from the shoulder and one tendon from below extends upward between these two; fibers just long enough to give the needed extent of movement pass diagonally across from the upper to the lower tendon, giving a bipenniform muscle. Many examples of this plan

of structure will be noticed as we proceed with the study of individual muscles. Probably the most notable example is the gastrocnemius (Fig. 113), which contains several penniform sheets and bundles formed into a well-rounded muscle.

It is easy to get a fair estimate of the strength of longitudinal muscles, for by cross-sections made in the dissecting room the area can be readily obtained with a fair degree of accuracy, and the parallel direction of all the fibers makes it easy to get cross-sections at right angles to the fibers. When we wish to know the strength of a penniform muscle the problem is very different, for a simple cross-section of such a muscle is oblique to the direction of its fibers and may not include half of them. In complex cases there is no apparent way to get the true cross-section. This method of learning about the strength of muscle is also lacking in that it gives us no knowledge as to the condition of the muscle and we have to assume it to be some arbitrary percentage of what it ought to be to make an estimate at all. Another way to determine muscular strength is by using a dynamometer. There are two types of dynamometer used for this purpose: one to test the muscular system as a whole and the other to test isolated groups of muscles. The first type of dynamometer is illustrated by the kind used in colleges to test the strength of lift (Fig. 6); the second by the kind used to test strength of grip. The former is useful to test a man's general strength, and requires but little time; if we wish to know how a man's strength is distributed we have to use a form of dynamometer that will test the strength of each muscle group separately (Fig. 7). This method does not give the actual pull of each muscle but its effective pull through its leverage as it normally works; this can be compared with the strength of other men, giving us after all a fair estimate of condition.

Fig. 6.—Use of a dynamometer for testing the general strength of the muscular system.

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A muscle can exert its greatest force when it is fully extended, and as it shortens its force diminishes. It follows that if we load a muscle with all it can lift it will be able to lift it but a short distance. The question arises, how large a load should be put upon a muscle if we wish it to work with best results? This is a problem frequently tested out in the physiological laboratory, using the

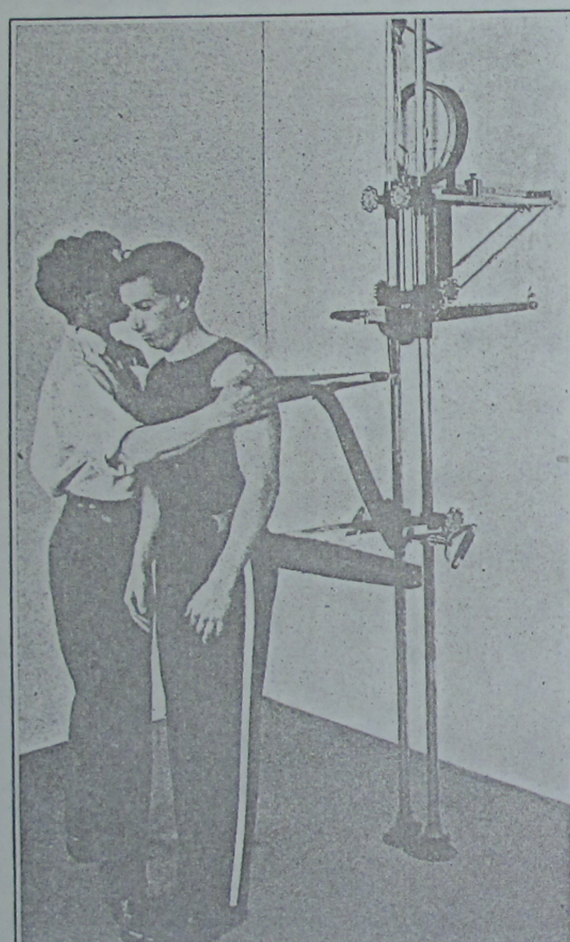

FIG. 7.—Use of a dynamometer for testing the strength of separate muscle groups. The abdominal group is being tested. (Kellogg.)

muscles of frogs. The following table shows the type of result uniformly obtained from this test. The muscle is given a constant stimulus:

Weight.	Height.	Work.	Weight.	Height.	Work.
0	10	0	6	5	30
1	10	10	7	4	28
2	9	18	8	3	24
3	8	24	9	2	18
4	7	28	10	1	10
5	6	30	11	0	0

The column marked weight gives the number of gram weights used to load the muscle in the successive tests; the figures for height are the numbers of centimeters the weight was lifted; the figures for work are the products of weight and height in gram-centimeters. Notice that the work accomplished is least with the lightest and heaviest weights, and is most when the weight is about half of what the muscle can lift. It means that when we use muscle to get work done it pays to take moderate weights, avoiding the extremely light and extremely heavy ones. This has been applied in manual labor, and certain companies who employ shovelers furnish them with shovels that will hold just 21 pounds, which has been found to be the most favorable weight for the average man. There is reason to believe that such a load for a muscle is not only best for efficiency but also best for training, although it would appear to be wise to use heavier loads for a small part of the time.

An important condition is illustrated in the last line of the above table, where the weight is too great for the muscle to lift. If we apply the formula $W = F \times D$ we get 0 for the work. This means that in the mechanical sense no work is done, although if we watch the muscle we see that it contracts and exerts force, which involves destruction of tissue and consequent fatigue. It is usual to say, in explanation of the apparent contradiction, that in such a case a muscle does internal work but no external work. We shall see later that the muscles of the body do a great amount of useful work without causing motion, as illustrated in standing, sitting, holding a weight in the hand or on the shoulder, or hanging by the hands; also in holding a bone solidly in place that it may serve as a firm support for the pull of another muscle. Such contractions are called static contractions; they result in some muscular development but are not so good for that purpose as those that cause motion.

A further extension of the same principle is shown when we use muscles to oppose a movement but not strongly enough to stop it, as in lowering a weight slowly, walking down stairs or in wrestling with a stronger opponent. Such actions of muscle may be called lengthening contractions to distinguish them from the static and from the usual shortening contractions. Each kind of action has its use. We may summarize by saying that muscular work may involve shortening, static, or lengthening contractions according as the force of contraction exceeds, equals, or is less than the resistance.

Football players have known for many years that a man can start quicker and push harder if he is in a crouching posture, and a few years ago it was discovered that sprinters can get the quickest start by assuming a similar attitude. This is for the same reason

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